

Evaluation of marginally non-compliant dam filter materials using the No-Erosion Filter test method

Robert Kingsland¹

Jamie Anderson²

Andrew Russell²

David Brooke³

¹Parsons Brinckerhoff, Newcastle

²Parsons Brinckerhoff, Singleton

³GHD, Artarmon

This paper presents the methods, observations and results from a programme of No-Erosion Filter (NEF) testing for the evaluation of a manufactured filter aggregate product that did not conform to normally accepted D_{15F} grading limits. Base materials tested include both dispersive and non-dispersive soils. The results are compared against published no-erosion, excessive erosion and continuing erosion thresholds. The paper comments on the validity of the adopted thresholds and the effectiveness of the NEF test as a filter evaluation method.

Keywords: dam, filter, test, no-erosion

Introduction

The key filter design criterion used for controlling internal erosion is to limit the void size which is normally defined by the D_{15F} value; i.e. the particle size at which 15% of the filter particles are finer by mass. The maximum D_{15F} is determined by the base soil (i.e. the soil next to the filter) grading and dispersibility (Fell *et al.* 2005).

The filter design for a new mine water dam in the Hunter Valley, NSW incorporated this requirement in the required grading envelope. When this grading envelope was transposed into a specification table an error was made which resulted in the specified maximum D_{15F} being greater than that which was nominated by the design. This error was not detected until a substantial quantity of filter material was delivered, stockpiled and some placed on-site. Some of the supplied product also had a D_{15F} value that was even higher than the specification. The authors were then faced with finding an alternate approach to evaluating the suitability of the specified and delivered filter materials.

The grading limits used in the design of filters have been developed with reference to filter performance testing where water is passed under a pressure head through a hole or slot in a base soil placed directly against the filter material being evaluated. One such test, used extensively by the US Soil Conservation Service, is described in Sherard and Dunnigan (1985) and is referred to as the "No-Erosion Filter Test".

The No-Erosion Filter (NEF) test was used to evaluate the performance of the specified grading envelope and supplied product.

This paper presents the results of the NEF testing performed on the supplied filter product and a manufactured filter replicating the coarse limit of the specification grading. The testing outcomes are discussed and compared with published erosion thresholds and conclusions drawn about the applicability of the test and the appropriateness of the published erosion thresholds.

Background

An open cut coal mine in the Hunter Valley, NSW required a new 3,000 ML mine water storage dam to be constructed as part of their site-wide water management system. The dam is now the main 'out-of-pit' storage. It is used to store excess water from the open cut or other operational areas. The water is either used in the coal preparation plant, pumped to other dams on site for reuse or discharged via a licensed discharge point. As is common in mining applications, the area identified as available for the dam was largely a function of there being no economical resource to be extracted from the area in the foreseeable future. The area was somewhat constrained by other infrastructure and a property boundary resulting in a relatively long embankment of approximately 1,200 m with an average height above ground level of 13 m and a 5 m deep cut-off trench. Due to the topography of the area, approximately 1.5M m³ was excavated to create a storage with roughly a third of the excavated material going into the main embankment and two discrete tailwater embankments. The tailwater embankments provide high storage level confinement within the mine boundary. Filters were included in the main earthfill embankment due to the embankment height and the consequence rating.

Following extensive field and laboratory investigations and desktop work a suitable filter material was specified. Unfortunately an error was made while transposing data from the graph to the table in the design report. This was then transferred to the technical specification issued for the project. Table 1 presents the design and specification gradings and these are presented graphically in Figure 1.

The design grading, would have met the no-erosion (Fell *et al.* 2005) grading criterion of D_{15Fmax} of 0.5mm for dispersive category 2A base soils. However, the D_{15Fmax} for the specification grading was approximately 0.85mm.

Table 1: Design and specification gradings

Sieve (mm)	Design coarse limit (% passing)	Spec coarse limit (% passing)	Design fine limit (% passing)	Spec fine limit (% passing)
37.5	100		100	
26.5	95		100	
19	90	100	100	100
13.2	85		100	
9.5	80		100	
6.7	75	70	98	94
4.75	70	60	94	84
2.36	60	40	84	75
1.18	40	20	75	64
0.6	20	10	64	58
0.425	10		58	
0.3	6	6	49	49
0.15	3	3	26	26
0.075	0	0	2	2

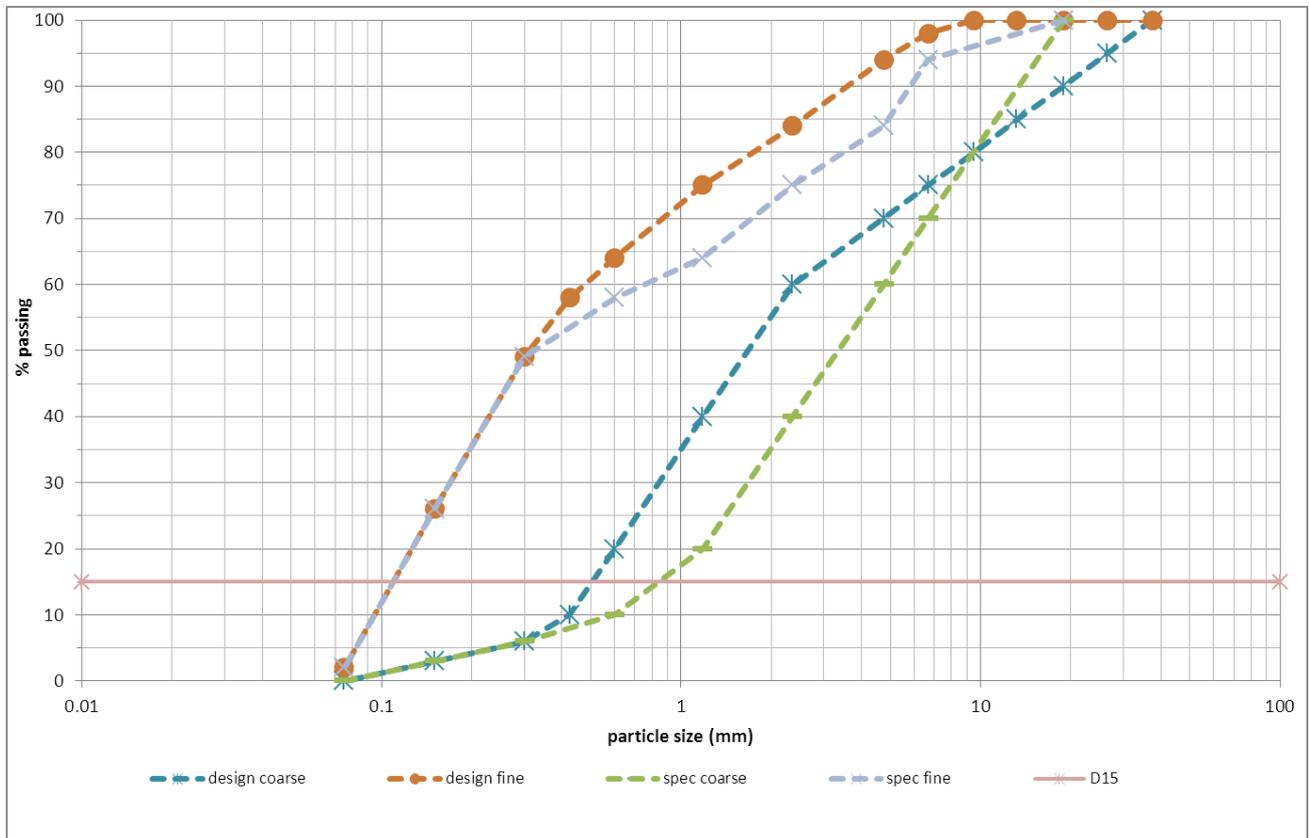


Figure 1: Design and specification grading envelopes

The error was identified when independent testing of the site delivered filter material indicated that the filter product did not meet the design grading. This then prompted a review of the contract specification which is when the transposition error was noted. By this time large quantities of filter material had been delivered to site and placed.

An assessment of both the suitability of the material on site and the material that matched the specification grading was required.

Given that the filter grading specification may have permitted some erosion and the site soils were dispersive, it was decided that a number of NEF tests be performed using the delivered product and a manufactured fine filter material (replicating the coarse limit of the specification grading) against the actual base soil.

The results allowed conclusions to be drawn about the anticipated performance of the filter.

No-Erosion Filter (NEF) test methodology

The NEF testing was performed in a Sydney based soils laboratory. The NEF test used is based on procedures described by Sherard and Dunnigan (1989). The Sherard and Dunnigan test apparatus is illustrated in Figure 2. The test evaluates the effectiveness of the filter zone to stop erosion from a concentrated leak through the base soil from the embankment core should a concentrated leak form along a crack or poorly compacted zone.

The test apparatus used is a 125 mm diameter Perspex cylinder for fine grained filters or a 293 mm cylinder for coarse grained filters.

The coarse and fine grained filter test apparatus are shown in Figure 3.

Sample preparation

Preparation of the clay core material to a target moisture content is critical to the performance of the test. Adequate curing of the clay core material and removal of coarse material may be required to prevent gravel from blocking the formed hole.

Filter material and bottom drainage material are also cured for at least 24 hours prior to the test. Side protection sand is placed dry.

Test set up

Bottom drainage is placed moist and compacted.

Filter material is placed moist and to a target density. Care is required to avoid segregation of the filter,

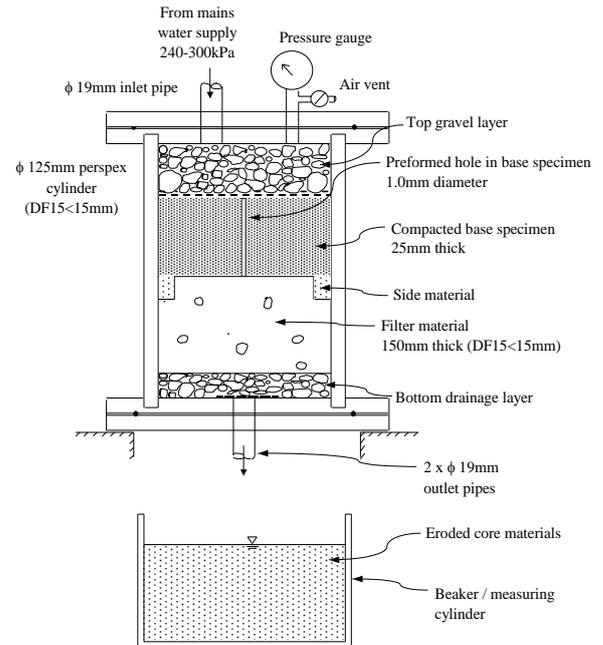


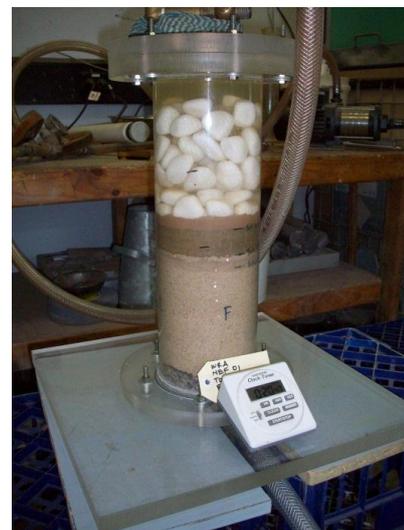
Figure 2 – No-erosion test apparatus (Sherard and Dunnigan, 1989)

especially when using the 293 mm diameter cylinder. The final layer requires a steel or plastic ring to be placed on the filter to allow for the side protection material. The filter is first compacted inside the ring. The ring can then be removed, if possible, and the side protection sand placed around the outside of the filter. The ring may have to stay in place whilst filling and the ring removed incrementally.

Care needs to be taken during compaction of the final layer of filter to avoid large particles being placed directly underneath the hole through the clay core material.



293mm NEF Test



125mm NEF test

Figure 3 Coarse grained filter (293mm) and fine grained filter (125mm) NEF test apparatus

The clay core material is compacted to a target moisture content and density and a small amount of potter's clay is used to seal the top of the cylinder and clay interface. The moulded test set up is allowed to rest overnight.

For the standard (125 mm diameter) test cell, Sherard and Dunnigan procedure uses a 1 mm hole through the clay core. This hole is susceptible to closure prior to testing due to clay swelling during the filling of the cylinder and also blockage during the test. A 2 mm hole is preferred to avoid these blockages. The hole is formed in the rested specimen by using a stiff steel rod (bicycle spokes are excellent) pushed through the clay core. Excessive twisting of the rod is avoided. The rod is inserted into the filter at least 1mm to ensure that the hole remains open and is not plugged by clay material pushed through by the rod. In the case of the coarse grained filter test cell a 5 mm hole was formed in the base soil. This may be formed using a rod or drill bit.

Coarse sand & fine gravel can cause issues during this process, therefore the top gravel layer is placed on top of the clay core, the cylinder filled and the test commenced with no delay which can result in the clay core swelling in some instances. A test pressure of around 400 kPa is preferred. An initial flow rate surge will occur. It is at this point where complete failure of the filter may occur.

The test is normally let run for at least 60 minutes depending upon filter performance. Flow rate measurements, colour and post-test observations are recorded as per Sherard and Dunnigan (refer Figure 4).



Base of clay core after test



Eroded hole after test

Figure 4 – Post NEF test observations



After test extrusion

Figure 4 – Post NEF test observations (continued)

Specific attention is given to the colour of the filter directly underneath the clay core and the hole shape in the clay core. Extrusion is performed by inverting the cylinder on a suitable frame and slicing away the layers until the clay core is exposed

Test problems

Insufficient compaction of the base and filter material may result in excessive settlement of the filter allowing a gap to form between the filter and the clay core. Insufficient compaction of the clay core material at the cylinder interface may allow preferential flow down the side of the cylinder. Coarse particles present in the clay may block the hole if a flow occurs.

When using the 293mm Perspex cylinder, banding of the cylinder is required to reduce side wall flex which can allow side drainage and cylinder failure. A hole of 5mm diameter is used in order to reduce the likelihood of gravel blocking the exit. It also assists to increase the amount of eroded material which can be captured by the filter. The size and weight of the 293mm x 1000mm high cylinder requires the preparation and handling methods to be modified.

If a conventional NEF test does not produce a result due to the lack of eroded material being deposited, a slurry mixture can be used in place of the compacted clay core material.

Results

Base soil testing

Soil used in the construction of the dam was sourced from the residual and weathered coal measures siltstones from within the storage area. Design phase site investigation showed that some of the soils were defined by particle size distribution testing as silts; however the clay content of these soils was considered high enough for Zone 1 use and the suitability was confirmed with compaction testing. Fines content was typically 65% to 85%.

The clayey soils were also identified by the site investigation as being prone to dispersion and internal erosion with some Emerson dispersion numbers of 2, but mostly 4 and 5. Pinhole dispersion results were mostly D1 and D2 (i.e. dispersive). The soils had typical liquid limits

in the range 35% to 50% and plasticity index values typically in the range 20% to 40%.

At the time that the filter grading issue was identified, construction was under way in the general foundation and cut-off foundation areas of the main embankment. Base soils for the NEF testing were sampled from the downstream embankment foundation and from within the clay core. Base soil index testing indicated that the sampled clays were generally medium to high plasticity, with varying degrees of dispersion potential (pinhole dispersion classes of ND1 – non-dispersive and D2 - dispersive).

The foundation soil from Chainage 460 was identified as the most dispersive of all base materials tested (Emerson Class 1 in distilled water, Emerson Class 2 in Sydney tap water and Pinhole Dispersion Class D2). The grading for the foundation base soil is shown in Figure 5.

Filter gradings

Testing was completed in two rounds – firstly with site sampled filter materials, and secondly with a manufactured filter product.

The first stage of testing matched base soil and filter material from adjacent locations. Base soils from the core were matched to filter materials sampled from the adjacent vertical filter and base soils from the foundation were matched to filter materials sampled from the adjacent horizontal filter.

When the grading results indicated that the site sampled product was coarser than the specification and the tested combined base soils were non-dispersive, a second round of testing was carried out.

This round used a filter material that was manufactured using the site sampled filter material to match the grading of the coarse boundary of the specification filter envelope and matched it to the most dispersive of the sampled base soils (i.e. the foundation soil from Chainage 460).

The grading of the site sampled filter materials and the manufactured filter with reference to the specification is presented in Figure 5.

NEF results

The interpretation of filter performance based on the NEF test results requires a consideration of:

- initial flow rate
- clarity of effluent water and time for the water to clear
- evidence of erosion in the base soil sample
- evidence of erosion of the base into the filter material

The results allowed conclusions to be drawn about the anticipated performance of the filter.

The round 1 NEF tests on the site delivered filter materials recorded the following observations:

- little change in the size of the starting hole
- low initial flow rates
- effluent was initially dirty but became clear within approximately 30 minutes
- no significant erosion of base soil into the filter was observed (some slight penetration noted in NEF2 and NEF3)

The filter eventually sealed with no significant erosion of base soil into the filter indicating satisfactory filter performance.

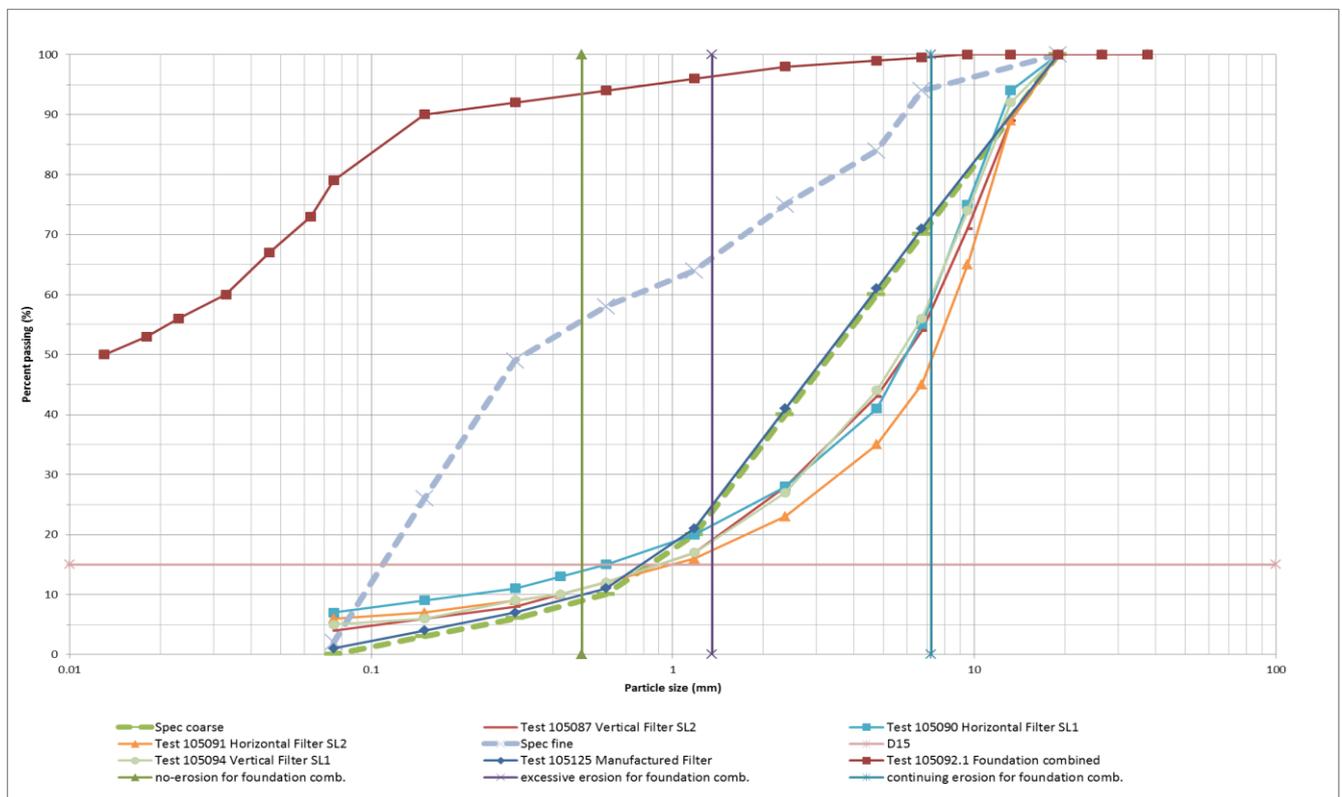


Figure 5 Filter grading results compared against the specification

The results of the first round of NEF testing indicate some erosion but sealing which is consistent with the Fell et al (2005) “some erosion” definition; i.e. filter seals after “some” erosion of the base material.

The round 2 NEF tests on the manufactured filter grading recorded the following observations:

- enlargement of the starting hole and some conical erosion of the base at the filter interface
- flow rates were moderate but decreased with time
- effluent was initially dirty but became clear within approximately 60 minutes
- no penetration of base soil into the filter was observed.

Some erosion of the base soil occurred, as may be expected given that the D_{15F} exceeded the no-erosion criterion and the base soils were dispersive. However, no significant penetration of base soil into the filter occurred and the filter sealed in time indicating successful filter performance.

The results of the second round of NEF testing generally indicate some erosion but sealing which is consistent with the Fell et al (2005) “some erosion” definition; i.e. filter seals after “some” erosion of the base material. The NEF test results for the delivered and manufactured filter materials are presented in Table 2 and Table 3 respectively.

Filter evaluation

Foster and Fell (2001) provides criteria for “no-erosion”, “excessive erosion” and “continuing erosion” boundaries.

Table 2 NEF test results for delivered filter materials – prediction and performance

Test No.	NEF1	NEF2	NEF3	NEF4
Base soil source (dispersion class ¹)	Combined core (ND1, 4, 4)	Combined core (ND1, 4, 4)	Combined foundation (ND1, 4, 1)	Combined foundation (ND1, 4, 1)
Filter source (D15)	Vertical filter sub-lot 1 (1.18mm)	Vertical filter sub-lot 2 (0.9mm)	Horizontal filter sub-lot 1 (0.6mm)	Horizontal filter sub-lot 2 (1.0mm)
Hole size at end of test (mm)	3	4	2 to 3	2 to 3
Time to flow clear (minutes)	31	33	12	17
Flow rate (L/min)	Initial 0.8; reducing to 0.1 prior to drainage path developing	Initial 1.9; increasing to 3.0; reducing to 1.9	Initial 0.71, reducing to 0.05	Initial 0.13, reducing to 0.08
Comments	Test terminated due to the formation of a drainage path around the filter	water clear and flow rate decreases and stabilises after 25 min; no significant penetration of base into filter	Filter material has slight colour from 30mm below clay.	
NEF Test Assessment	Filter sealed; some erosion	Filter sealed; some erosion	Filter sealed; some erosion	Filter sealed; no erosion
Erosion boundaries ² (mm)	0.5/2.7/12	0.5/2.7/12	0.5/1.35/7.2	0.5/1.35/7.2
Predicted behaviour	some erosion	some erosion	some erosion	some erosion

Note: 1. Reported as pinhole dispersion class and Emerson Class tested in Sydney tap water and Emerson Class tested in distilled water

2. No-erosion/excessive erosion/continuing erosion. The "no-erosion" boundary is defined by the D_{15Fmax} of 0.5mm (if D1, D2, Emerson Class 1 or 2), or else 0.7mm; the "excessive erosion" and "continuing erosion" boundaries are defined by a D_{15Fmax} value calculated as a multiple of D_{90B} or D_{95B}

For the subject dam base soils, the “no-erosion” boundary is defined by the D_{15Fmax} of 0.5mm, the "excessive erosion" and "continuing erosion" boundaries are defined by a D_{15Fmax} value calculated as a multiple of D_{90B} or D_{95B} . For the foundation soil base used in conjunction with the manufactured filter grading (to assess the suitability of the specification) the “excessive erosion” and “continuing erosion” boundaries are defined by D_{15Fmax} values of 1.35 mm and 7.2 mm respectively. These threshold values are shown in Figure 5. Therefore, since the specification D_{15Fmax} value of 0.85mm falls between the “no-erosion” and “excessive erosion” boundaries, “some erosion” is likely for filters close to the specification coarse limit. Foster and Fell (2001) defines these boundary terms as follows:

“no-erosion” – filter seals with practically no-erosion of the base material

“some erosion” – filter seals after “some” erosion of the base material

“excessive erosion” – filter seals, but after “excessive” erosion of the base material

“continuing erosion” – the filter is too coarse to allow the eroded base materials to seal the filter.

The results of the NEF testing generally indicated some erosion but sealing which is consistent with the Foster and Fell (2001) “some erosion” definition; i.e. filter seals after “some” erosion of the base material.

Table 3 NEF test results for manufactured filter materials – prediction and performance

Test No.	NEF5	NEF6	NEF7
Base soil source (dispersion class ¹)	Foundation Ch 460 (D2, 2, 1)	Foundation Ch 460 (D2, 2, 1)	Foundation Ch 460 (D2, 2, 1)
Filter source (D15)	Manufactured filter (0.85mm)	Manufactured filter (0.85mm)	Manufactured filter (0.85mm)
Hole size at end of test (mm)	5 to 7	3 to 8	3 to 6
Time to flow clear (minutes)	45	56	48
Flow rate (L/min)	Initial 2.7, reducing to 0.3	Initial 2, reducing to 0.03	Initial 1.6, reducing to 0.02
Comments	2 erosion paths formed around base sample	Some clay deposit on filter. Erosion of clay forming a 8mm void next to the filter.	
NEF Test Assessment	Filter sealed after some erosion	Filter sealed after some erosion	Filter sealed after some erosion
Erosion boundaries ² (mm)	0.5/1.35/7.2	0.5/1.35/7.2	0.5/1.35/7.2
Predicted behaviour	some erosion	some erosion	some erosion

Note: 1. Reported as pinhole dispersion class and Emerson Class tested in Sydney tap water and Emerson Class tested in distilled water
 2. No-erosion/excessive erosion/continuing erosion. The "no-erosion" boundary is defined by the D_{15Fmax} of 0.5mm (if D₁, D₂, Emerson Class 1 or 2), or else 0.7mm; the "excessive erosion" and "continuing erosion" boundaries are defined by a D_{15Fmax} value calculated as a multiple of D_{90B} or D_{95B}

Erosion thresholds

The NEF testing program involved the evaluation of the performance of the filter samples with a range of D_{15F} values against base soils sampled from the embankment core and dam foundation areas with varying degrees of dispersion potential as determined by Pin-hole and Emerson dispersion testing. This test data has been compared with the “no-erosion”, “excessive erosion” and “continuing erosion” boundaries as defined by Foster and Fell (2001). The results of this comparison are presented in Table 2 and Table 3 for site delivered and manufactured filter materials respectively.

What the results comparison shows is that:

- All filter materials have a D_{15F} value that exceeds the “no-erosion” threshold, but by varying degrees
- All filter materials have a D_{15F} value that is less than the “excessive erosion” threshold
- All NEF tests indicated some erosion of the base soil but filters sealed
- No indications of excessive erosion were observed although a greater amount of erosion occurred for the dispersive soils

The results of the NEF testing indicated “some erosion” with filter sealing. The predicted performance of the tested filters was “some erosion” with filter sealing; i.e. the D_{15F} values lay between the “no-erosion” and “excessive erosion” sizes. Therefore the Foster and Fell (2001) “no-erosion” and “excessive erosion” thresholds appear appropriate for the materials tested.

However, the greater levels of erosion observed for the dispersive base soil suggests that some downward adjustment of the “excessive erosion” threshold may be warranted where dispersive soils are encountered. Further testing with filters with varying D_{15F} up to the nominated threshold value is required to confirm this.

Conclusion

No-Erosion Filter (NEF) testing was employed to assess the suitability of a filter aggregate product that did not conform to normally accepted D_{15F} grading limits.

The design “no-erosion” boundary for a new mine water dam project in the Hunter Valley was defined by a D_{15Fmax} of 0.5mm. However, the delivered and placed filter product had D_{15F} values in the range of 0.6 mm to 1.18 mm and the specification grading erroneously had a D_{15F} of 0.85 mm.

The NEF testing showed that all the tested filter materials eventually sealed with no significant erosion of base soil into the filter.

The results of the NEF testing indicated some erosion with sealing which is consistent with the Fell et al (2005) some erosion definition; i.e. filter seals after “some” erosion of the base material.

Based on the outcome of this testing (and other filter specification compliance testing), the following actions were taken:

- The placed filter materials were removed. These materials did not meet the specification requirements; i.e. they were too coarse in the finer fractions (as

reflected by the high D_{15F} value) and the fines content was too high.

- Blended delivered material meeting the specification grading was used in nominated less critical locations; e.g. in vertical filters where embankment heights were less than 5m, or in horizontal blankets in longitudinal strips not adjacent to the downstream toe.
- All new filter products delivered to site complied with the original design grading, i.e. with a D_{15Fmax} of 0.5mm. This represented the majority of the filter product used.

The NEF test therefore proved to be a valuable tool for evaluating the erosion performance of a filter material that was marginally non-compliant with respect to the D_{15F} grading limit. It is noted that the filter material accepted was required to comply with the permeability and fines content requirements of the specification. Furthermore, the authors do not advocate the use of the NEF testing as a replacement for standard specification compliance test methods and adherence to the normally accepted design criteria.

The NEF testing programme allowed the supplied and specified product to be compared against the “no-erosion” and “excessive erosion” and “continuing erosion” boundaries as defined by Foster and Fell (2001).

This comparison placed the supplied and specified filter materials between the “no-erosion” and “excessive erosion” thresholds suggesting that the filter would seal after “some” erosion of the base material. This predicted performance was verified by the NEF testing of filters where some erosion with filter sealing was observed. This concurrence of prediction and performance suggests that the Foster and Fell (2001) “no-erosion” and “excessive erosion” thresholds appear appropriate for the materials tested with potentially some downward adjustment where dispersive soils are encountered.

Acknowledgements

The authors acknowledge the support and permission of Parsons Brinckerhoff and GHD for the preparation of this paper.

We also wish to thank Brian Walford for his valuable review feedback, Lorraine Kingsland for proof reading and Alicia Sullivan for the production of the final document.

References

- Fell, R., MacGregor, P., Stapledon, D., Bell, G, 2005. *Geotechnical Engineering of Dams*. A.A. Balkema Publishers.
- Sherard, J.L.; Dunnigan, L.P., 1985. Filters and Leakage Control in Embankment Dams. *In: Volpe, R.L.; Kelly, W.E. (eds.) Seepage and Leakage from Dams and Impoundments*, ASCE.
- Sherard, J.L, and Dunnigan, L.P., 1989, Critical Filters for Impervious Soils. *Journal of Geotechnical Engineering, ASCE*, 115(7), 927-947
- Foster, M.; Fell, R. 2001 Assessing Embankment Dam Filters that do not Satisfy Design Criteria, *ASCE Journal Geotechnical and Geoenvironmental Engineering*, Vol. 127, No. 5. 2001.